In-Flight Leak Detection: A Hydrogen/Oxygen Leak-Imaging Sensor

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Hydrogen and oxygen propellant leaks are difficult to detect in a spacecraft environment due to the issues of size, weight, and availability of sensors. Tracer gas techniques can identify leaks during the initial checkout phase, but cannot identify leaks caused by cryogenic cool-down of joints and cannot function when the spacecraft is fueled and on the launching pad (or in flight). A need exists for various types of sensors, including imaging sensors, that can, for example, visualize a leak from a joint.

Optical leak sensors offer the advantages of fast detection, remote detection, and lack of contamination problems. Hydrogen is difficult to detect optically because it lacks an absorption spectrum (due to the symmetric, diatomic-molecule structure of this gas). The strongest optical signature from hydrogen and oxygen is the Raman scattering effect. Spontaneous Raman scattering is a very weak effect: in an imaging context, every photon of probe laser light may return 10^{-16} photons of Raman signal light from a 1-atmosphere (pressure) hydrogen leak.

Such detection schemes are actually well within the limits of conventional low-level light-detection techniques. These techniques include pulsed probe lasers and time-gating of single-photo light detectors (in the 5-nanosecond range) and optical filters to reject the probe laser light and stray background light. The wavelength-shifting property of Raman scattering is crucial in this context, as it allows the signal light to be isolated from the probe light.

The caveat in the preceding scenario is the word “conventional.” When performing spectroscopic work, one always keeps the optical axis of the detector perpendicular to the probe beam. With an imaging sensor, however, the optical axis of the detector must be precisely aligned to the axis of the outgoing probe beam, which introduces severe problems due to the fluorescence of metal surfaces in the field of view of the detector. Even a narrow-bandwidth, gated detector is easily overwhelmed by background fluorescence.

An innovation in the optical system (fig. 107) of an imaging detector can dramatically lower the background fluorescence problem. The concept involves focusing the probe laser to a point in open space and precisely aligning a pinhole fieldstop such that only light scattered from the focal region may enter the detector. This isolates the background fluorescence from the detector to a large degree. The innovation is called a “confocal” telescope, which allows limited three-dimensional imaging. A key part of the concept is that it allows probe laser intensities to be used that are far below the threshold for gaseous ignition.

The current status of the project is that a breadboard version of a confocal telescope has been constructed and that some data have been taken. The breadboard is 2 by 3 feet in size and contains a continuous-wave doubled-YAG probe source, photomultiplier tube and housing, and an optical scanner for fast scanning. A spacecraft sensor would be much smaller and more lightweight.

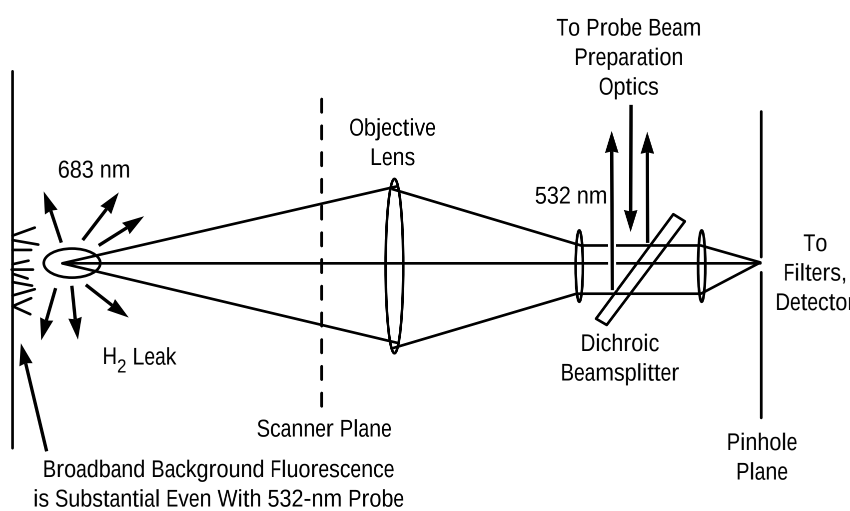

FIGURE 107.—Confocal telescope concept dramatically raises signal-to-fluorescence ratio.

In addition to the optical concept, one other critical component of this imaging technology is a fast-control system to manage the imaging process and display the processed data in real time. Conventional real-time operating systems are not fast enough to deal with the submillisecond event scales involved. Instead, hybrid software has been created that allows a fast-control system to be constructed on an MS–DOS environment. The software uses a 32-bit extended disk operating system and an architecture that prevents mode switching during interrupts and their associated overhead. The real-time part of the software will migrate to an embedded instrument-mounted system.

This technology is general in nature and can be commercialized in such areas as hydrogen facility leak detection, forensic analysis, and automated surface inspection. The technology is also a good starting point for more exotic technologies (e.g., stimulated Raman and Coherent Anti-Stakes Raman Spectroscopy techniques).

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Duryea, T.W. May 1992. Raman-Based Leak Detection. Proceedings of NASA Advanced Earth-to-Orbit Propulsion Technology Conference, MSFC.

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